Light Metals 2014
Edited by: John Grandfield
TMS (The Minerals, Metals & Materials Society), 2014

MICROSTRUCTURE AND MECHANICAL PROPERTIES OF 3003 ALUMINUM ALLOY WITH Mg AND Ni ADDITION

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Keywords: aluminum alloy; alloying element; microstructure; mechanical property; processing

ABSTRACT

A study of effects of adding elements and processing on the microstructure and mechanical properties of 3003 aluminum alloy has been carried out with a special focus on the effects of Mg alone and in combination with Mg and Ni in order to ensure it is able to withstand high temperatures. The additions of Mg or Mg+Ni can decrease grain size of the alloys under different processing conditions, and have AlMnFeSi and AlMnFeNiSi compound appearance. The tensile strength of 3003+0.3Mg and 3003+0.3Mg+0.2Ni alloys is increased to about 25% and 55% at room temperature, and 58%, 80% at 200℃ and 53%, 100% at 250℃ respectively. Especially, the creep resistance of 3003+0.3Mg+0.2Ni alloys has been significantly improved with a steady state creep rate decrease in two orders of magnitude. The relationships among microstructure, composition and properties are also discussed, which explains the reason of property improvement, especially high temperature performance.

INTRODUCTION

Due to its low cost, favorable strength/weight ratio, high thermal conductivity as well as good corrosion resistance, 3003 Aluminum alloy has been widely used in automobile heat exchange system, replacing traditional materials such as stainless steels and copper alloys [1, 2].

With the development of heat exchangers, the alloys used in the system are required to have good elevated temperature properties. For instance, the charge air coolers (inter-coolers) on automobiles equipped with turbochargers are demanded to work at an increased temperature. On the other hand, the several parts of a charge air cooler need to be brazed together, with the result that core alloy (3003 Al alloy) may be eroded by the melted Al-Si braze clad alloys. So there raise a request that the parts of a heat exchanger must maintain useable strength after experiencing a standard braze cycle and long term exposure to high temperature (about 200℃ or higher)[3, 4]. Therefore, the approaches should be investigated to enhance properties of the alloys, especially at elevated temperatures.

In this work, we investigate the effects of Mg alone and in combination with Mg and Ni on the microstructures and properties of 3003 Al alloy, and reveal relationships between adding elements and microstructures, in order to improve room and elevated temperature properties of the alloys effectively through minor Mg or Mg+Ni addition and proper processing[5-11].

EXPERIMENTAL

The aluminum alloys were added by different amounts of Mg and Ni, with chemical compositions in weight percent shown in Table I. These alloys were produced by melting raw materials in a graphite crucible in an electric resistance furnace up to 760℃. The molds (23cm×15cm×2cm) were made of gray cast iron and were preheated to 250℃ prior to pouring the molten alloys. C_2Cl_6 was chosen as refining agent and Al-5Ti-1B master alloys were used as grain refiners. The molten alloys were processed by vacuum degassing for 0.5 hr，then were poured into the mold at 720℃. The samples were treated by homogenization at 540℃ for 20 hr, then hot rolling at 450℃ to thickness of 7 mm in 4~5 rolling passes and cold rolling to the final thickness of 2 mm in 3~4

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rolling passes. After the final rolling, all samples were annealed at 400℃ for 1.5 hr. In order to simulate the brazing process, all samples were heated up to 600℃ and maintained for 10 min. At last, all samples were aged at 190℃ for 20 hr.

Table I. Chemical compositions (wt%) of the investigated alloys

Alloy	Mn	Si	Fe	Cu	Mg	Ni	Ti	Al
A	1.16	0.55	0.51	0.12	0	/	0.03	bal
B	1.15	0.59	0.53	0.13	0.33	/	0.02	bal
C	1.12	0.61	0.54	0.15	0.32	0.22	0.03	bal

The grain shape and size of the alloys was observed by a polarized light microscopy. Tensile tests were performed on a Zwick/Roell Z020 testing machine at room temperature, 200℃ and 250℃ respectively. The tensile strain rate was $0.1min^{-1}$. Creep tests were carried out on RD2-3 creep testing machine at 200℃ and 250℃ for 100 hr with loading stress of 50MPa (200℃)/35MPa (250℃).

RESULTS AND DISCUSSION

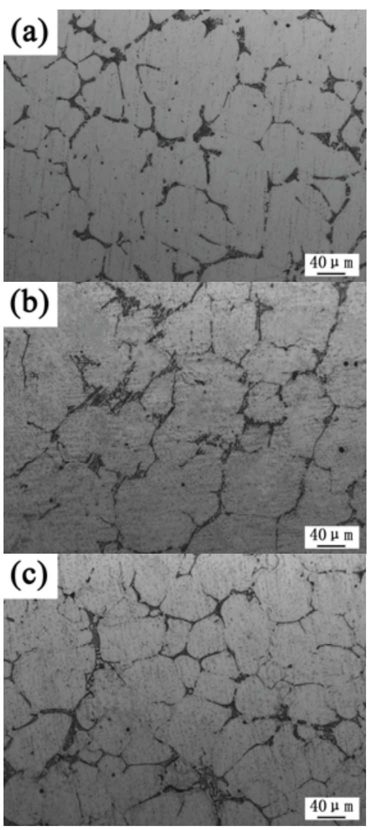

Figure 1. Optical microstructures of the as-cast samples: (a) 3003, (b) 3003+0.3Mg, (c) 3003+0.3Mg+0.2Ni.

MICROSTRUCTURES

The optical microstructures of the as-cast alloys consist of dendritic Al phase and inter-dendritic eutectics, do not change obviously with the addition of Mg and Mg+Ni, as shown in Fig.1. In order to eliminate the segregation in the as-cast samples and develop a favorable microstructure for rolling, all samples are homogenized at 540℃ for 20 hr. The grain shape and size of the alloys after homogenization are monitored by polarized microscopy, as illustrated in Fig.2. The structures of three alloys are homogeneous and the grain keeps equiaxed. Comparing 3003 and 3003+0.3Mg alloy, addition of Mg has no significant effect on grain size of alloys. However, when Mg and Ni are added together, the grain size decreases obviously, proving that addition of Mg and Ni can refine grains of the alloy.

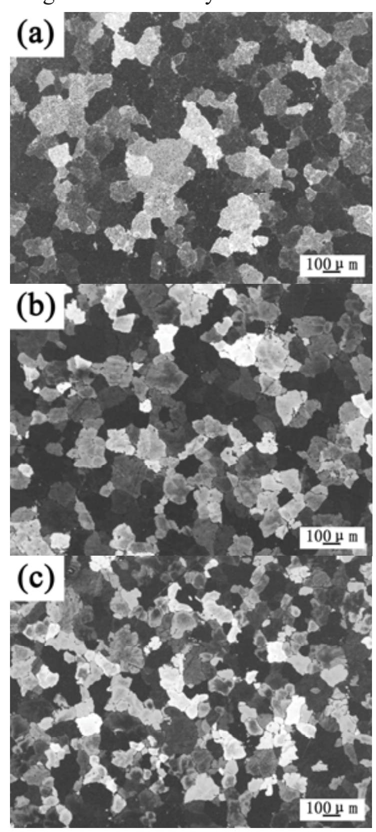

Figure 2. Grain shape and size of the alloys after homogenization: (a) 3003, (b) 3003+0.3Mg, (c) 3003+0.3Mg+0.2Ni.

The grain features of rolled samples after 400℃ annealing are shown in Fig. 3. The grain of three samples keeps long stripe shape. Obviously, 3003+0.3Mg and 3003+0.3Mg+0.2Ni alloys have finer grains than that of 3003 alloy, indicating that minor Mg and Ni addition can significantly decrease the grain of the samples under process of rolling and annealing. Interestingly, the grain of the samples do not become large and still keeps long stripe shape after 600℃ for 10 min brazing simulation and 190℃ ageing for 20 hr (called final processing), as shown in Fig. 4. This grain shape will be advantageous to creep behaviour.

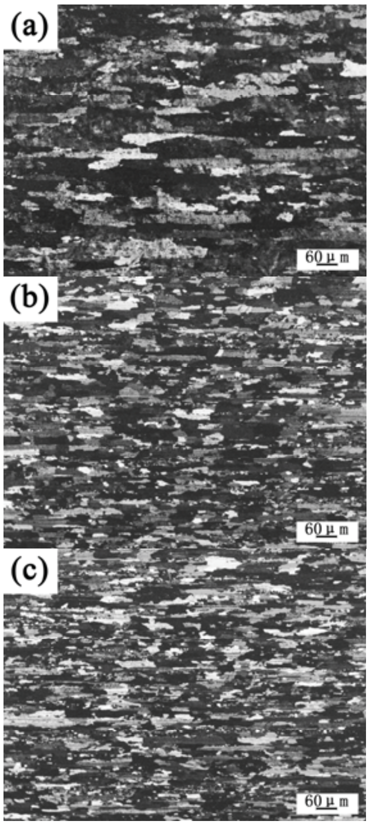

Figure 3. Grain features of rolled samples after 400℃ annealing: (a) 3003, (b) 3003+0.3Mg, (c) 3003+0.3Mg+0.2Ni.

Figs. 5 shows the SEM microstructures of the three samples after final processing. The compounds are almost granular with small size. According to our detected EDS data, these compounds in 3003 and 3003+0.3Mg alloys are AlMnFeSi phases, proving that minor Mg is mainly dissolved into Al matrix because of relative large solubility of Mg in Al. However, in 3003+0.3Mg+0.2Ni alloy, the compounds are AlMnFeSi phases and AlMnFeNiSi. This can be contributed to Ni has limited solid solubility in Al phase.

MECHANICAL PROPERTIES

Room temperature tensile properties of the three alloys under final processing are presented in Table II. Both Mg and Mg+Ni addition can significantly enhance the strength of the alloys. These results are attributed to grain refining, solution and second phase strengthening by Mg addition for alloy B, and to more notable second phase strengthening effect by Mg+Ni addition for alloy C. In alloy C, there are AlMnFeSi and AlMnFeNiSi compounds co-occurrence, which can effectively prevent the movement of dislocations. Therefore, alloy C has the highest strength under final processing.

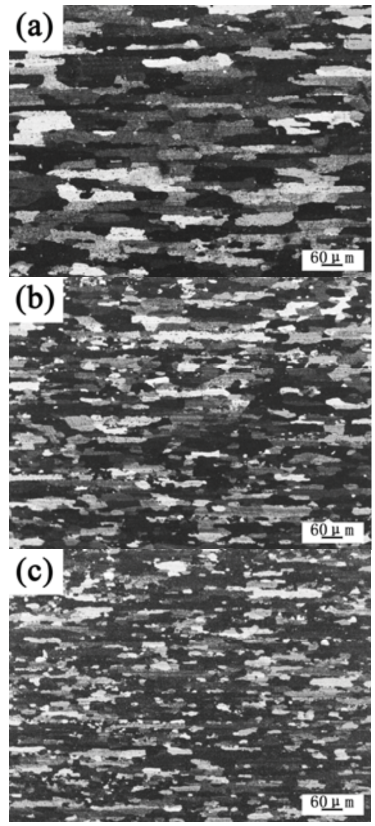

Figure 4. Grain features of the samples after 600℃ for 10 min brazing simulation and final ageing: (a) 3003, (b) 3003+0.3Mg, (c) 3003+0.3Mg+0.2Ni.

Table II. Room temperature tensile properties of three alloys

Alloy	YS/MPa	TS/MPa	Elongation/%
A	37.7	121.6	33.9
B	49.9	150.6	27.2
C	71.3	188.9	19.7

High temperature (200℃) tensile properties of the three alloys under final processing are summarized in Table III. With addition of Mg, the yield and tensile strengths increase apparently and the elongation decreases sharply compared with alloy A. The additions of Mg+Ni cause an obvious increase of strength than that of alloy B at elevated temperature. Actually, the bonding between atoms and dislocation motion resistance decrease at high temperature, which will lead to reduction in the strength. In this connection, the addition of Mg causes ageing strengthening effect and results in apparent enhancement of high temperature strength. When Ni is further added, the high melting point compound AlMnFeNiSi is formed. This phase is to be benefit of tensile properties at elevated temperature.

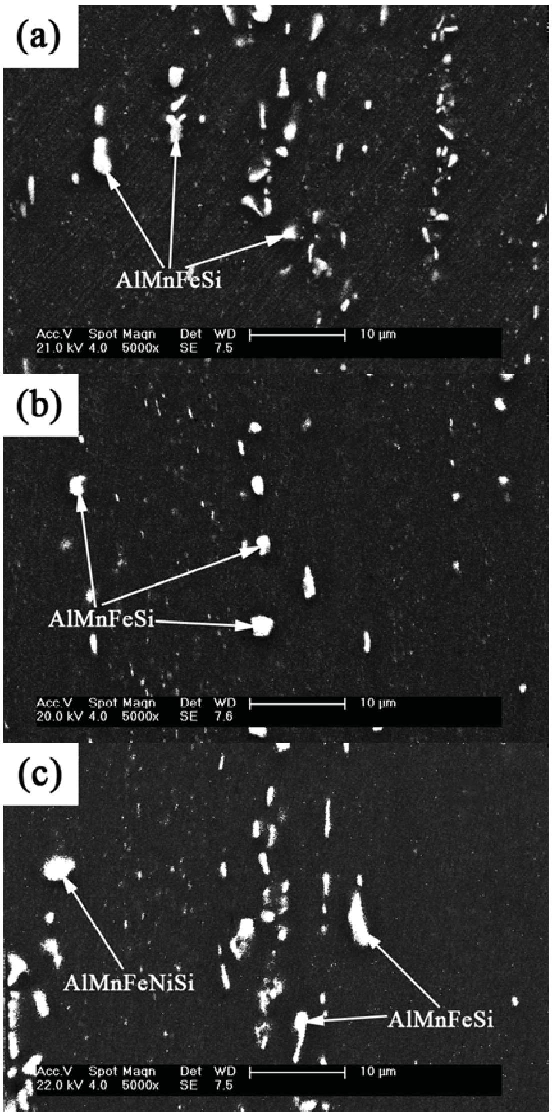

Figure 5. SEM images of the three alloys: (a) 3003, (b) 3003+0.3Mg, (c) 3003+0.3Mg+0.2Ni.

Table III. Tensile properties of three alloys at 200℃

Alloy	YS/MPa	TS/MPa	Elongation/%
A	26.6	68.7	60.3
B	42.7	109.3	38.7
C	55.5	130.1	29.7

The tensile properties of the three alloys at 250℃ are presented in Table IV. Comparing to the properties at 200℃, although the strengths of the alloys decrease at 250℃, both additions of Mg alone and Mg+Ni still enhance the high temperature strength obviously, and alloy C has the highest strength in this work.

Table IV. Tensile properties of three alloys at 250℃

Alloy	YS/MPa	TS/MPa	Elongation/%
A	22.5	50.7	79.8
B	34.6	78.3	68.4
C	47.1	101.6	52.4

The creep curves of the three alloys under 200℃ and stress of 50MPa are shown in Fig.6, indicating that 3003 alloy has the largest creep strain. The addition of Mg decreases the steady state creep rate sharply and leads to a lower creep strain than that of 3003 alloy. When Mg and Ni are added together, the steady state creep rate decreases even more. Alloy C has a minimum amount of deformation after creep test for 100 hr.

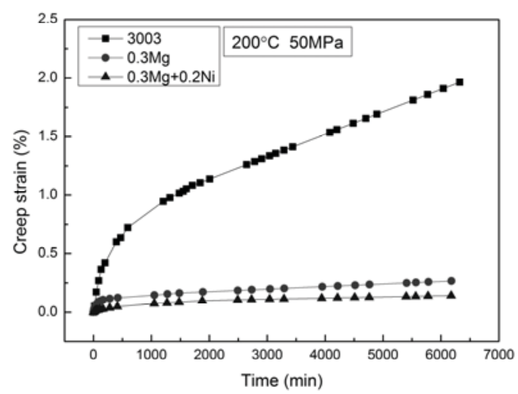

Figure 6. Creep curves of the three alloys under 200℃ and stress of 50MPa.

The creep curves of the three alloys under 250℃ and stress of 35MPa are shown in Fig.7. 3003 alloy almost has no steady state creep stage and is broken after short time. The addition of Mg decreases the steady state creep rate sharply, and alloy B isn't broken until sustaining for 100 hr. The addition of Mg and Ni further decreases the steady state creep rate and has the minimum amount of deformation. The steady state creep rate values of the three alloys under different creep test conditions are summarized in Table V. Comparing with 3003 alloy, the creep resistance of the alloys with Mg+Ni addition has been significantly improved with a steady state creep rate decrease in two orders of magnitude. The creep property improvements are related to multi-component compounds and long stripe shape grain. These two aspects may hinder the movement of dislocations and grain boundaries sliding.

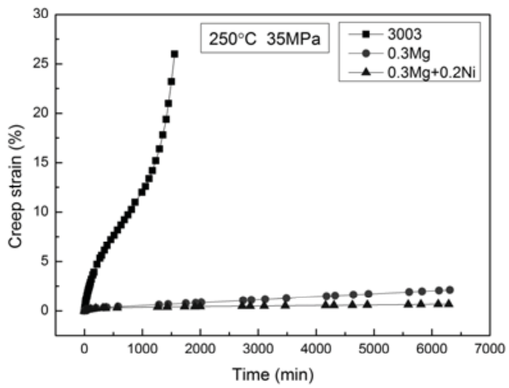

Figure 7. Creep curves of the three alloys under 250℃ and stress of 35MPa.

Table V. Steady state creep rate of three alloys (min^{-1})

Alloy	A	B	C
200℃ 50MPa	1.92×10^{-6}	2.21×10^{-7}	9.74×10^{-8}
250℃ 35MPa	9.28×10^{-5}	2.94×10^{-6}	5.44×10^{-7}

CONCLUSIONS

1. The additions of Mg or Mg+Ni into 3003 alloy can decrease grain size of the alloys under different processing conditions, and have AlMnFeSi and AlMnFeNiSi compound appearance. The addition of Mg mainly causes solid solution and ageing strengthening effect. Moreover, the addition of Mg+Ni enhances granular compound strengthening effect.

2. Both room temperature and high temperature strengths of 3003+0.3Mg alloy are increased obviously. The tensile strength of the alloy increases from 121.6MPa to 150.6MPa at room temperature, from 68.7MPa to 109.3MPa at 200℃, and from 50.7MPa to 78.3MPa at 250℃ respectively. The steady state creep rate the alloy decreases from $1.92\times10^{-6}min^{-1}$ to $2.21\times10^{-7}min^{-1}$ at 200℃ and from $9.28\times10^{-5}min^{-1}$ to $2.94\times10^{-6}min^{-1}$ at 250℃.

3. 3003+0.3Mg+0.2Ni alloy has the highest strength at room and elevated temperatures. The tensile strength of the alloy increases up to 188.9MPa at room temperature, up to 130.1MPa at 200℃ and 101.6MPa at 250℃. Steady state creep rate decreases to $9.74\times10^{-8}min^{-1}$ at 200℃ and $5.44\times10^{-7}min^{-1}$ at 250℃.

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